LONG RANGE LOCALIZATION OF IMPULSIVE SOURCES IN THE ATMOSPHERE AND OCEAN FROM FOCUS REGIONS IN SINGLE ELEMENT SPECTROGRAMS

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ABSTRACT

Waveguide propagation often displays transitions from one type of propagation to another as the mode number (or the take-off angle from a ray theory point of view) increases. An example of such a transition occurs when the boundary of the waveguide changes from being formed by refraction to being formed by reflection. When these transitions occur, they can result in broadband focusing of energy. These focus regions are observable in time series and in single element spectrograms. By measuring the difference in arrival times between these focus regions and knowing the group velocities involved, the range to a long-range impulsive source can be estimated, in the same way that time-of-arrival differences between seismic phases in single station seismograms are used to estimate epicentral distances. Examples of such broadband focusing in low-frequency acoustic propagation in the ocean and infrasonic propagation in the atmosphere are presented in this paper.

OBJECTIVE

The two programs whose contract numbers are listed above just started in July of this year. The first program is in the area of Infrasound Monitoring and the second is in Hydroacoustic Monitoring. The objectives of both projects are to use physics-based signal (and array, if applicable) processing techniques to locate and discriminate signals of interest to the International Monitoring System (IMS) for the Comprehensive Nuclear-Test-Ban Treaty (CTBT). Both research programs will involve theoretical development, numerical modeling, and comparisons of predictions with data from IMS, and IMS-like, stations to understand the benefits and limitations of various approaches. The purpose of this paper is to describe one of the physics-based techniques for estimating the range to a long-range impulsive source that will be investigated in these programs.

RESEARCH ACCOMPLISHED

Because both of these programs just started, the focus of this paper is to present some of the ideas behind the work to be undertaken. Part A is devoted to spectral focusing in ocean acoustic propagation and Part B discusses infrasound propagation in a canonical atmosphere.

A. Deep Ocean Sound Propagation

The first two authors of this paper are the Principal Investigators on "Long Range Localization of Impulsive Sources from Phase/Group Speed Transition Markers in Single Hydrophone Spectrograms", the new program in Hydroacoustic Monitoring at the Marine Physical Laboratory (MPL). The work in this project will expand upon the results to appear in Kuperman, D'Spain, and Heaney, 2000. Fig. 1 shows a spectrogram from the data collected by the shallowest element of the vertical hydrophone line array deployed during the Acoustic Thermometry of Ocean Climate (ATOC) program (ATOC Consortium, 1998; Colosi et al, 1999; Worcester et al, 1999). The ATOC signals have a bandwidth from 60 to 90 Hz, at the upper end of the frequency band of interest in hydroacoustic monitoring component of the IMS. Two broadband arrivals, separated in arrival time by around 5 s, can be clearly seen in the figure. The 3.5 Mm

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path over which this energy traveled is shown in Fig. 2 (Path "1"). Taking into account the receiver depth and calculating the effective group speeds for these two spectral focus regions, the time difference can be used to estimate the range to the source to within about 10 percent.

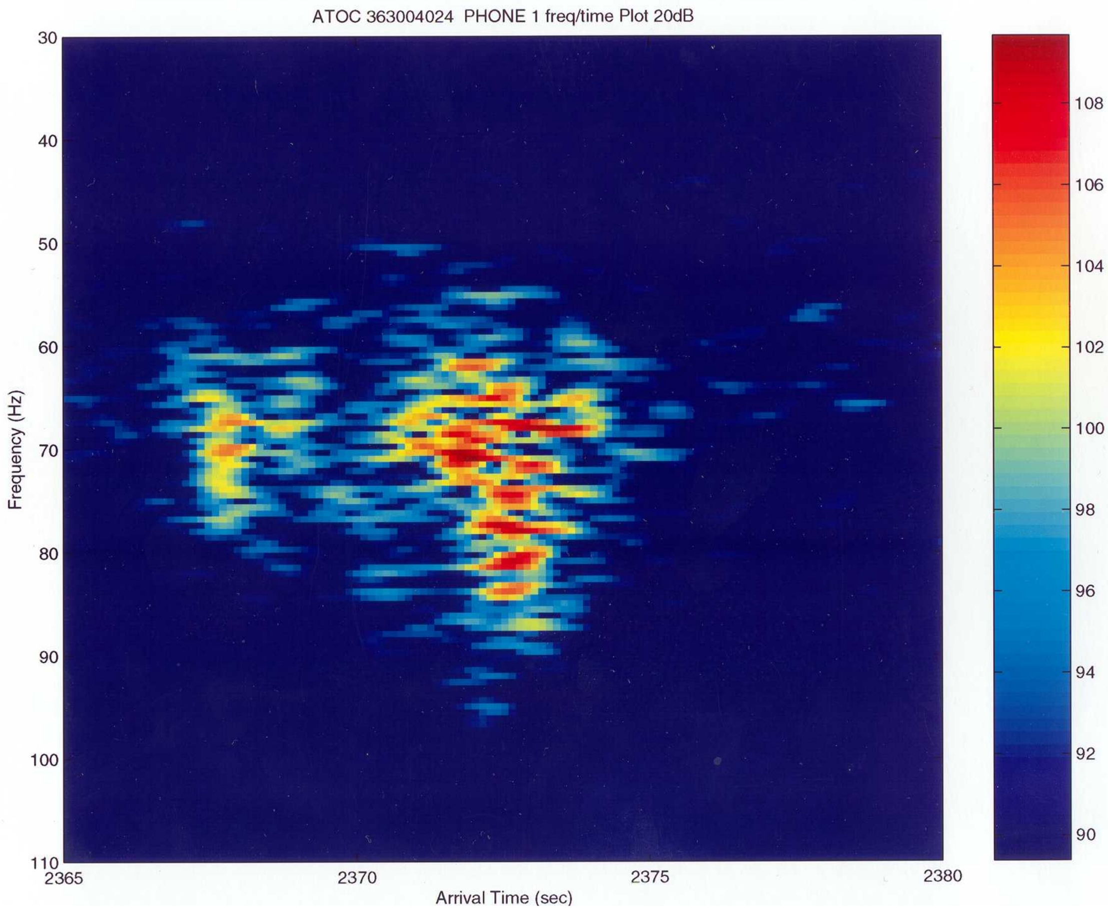

Figure 1. A spectrogram from the data from a single hydrophone collected during an Acoustic Thermometry of Ocean Climate (ATOC) transmission, after matched-filtering the received signal with the transmitted maximal length sequence (m-sequence) signal.

The focus regions in Fig. 1 are due to a combination of two effects. The first effect is the well-known broadband focusing that occurs at the extrema of the dispersion curves for a given mode of propagation. Examples of this type of focusing are the Airy phases associated with the minima in mode group velocity dispersion curves in shallow waveguide propagation and the G-waves in seismology arising from the characteristics of long-period Love wave dispersion (Aki and Richards, 1980). The second effect is related to the phenomenon of "weakly divergent bundle of rays" (WDBR) discussed in Brekhovskikh, Goncharov, and Kurtepov, 1995. The WDBR effect occurs when, from a ray theory point of view, an extremum exists in the ray cycle distance as a function of the ray take-off angle at the source. Only those rays associated with such extrema need to be considered when modeling received sound fields over megameter propagation distances in the ocean (Brekhovskikh, Goncharov, and Kurtepov, 1995). From a normal mode point of view, the extrema appear in the mode group velocity curves as a function of mode phase velocity (or equivalently mode number) at a single frequency. Under the WKB approximation, focusing across frequency at a given mode coincides with focusing across mode number at a given frequency. However, as frequency decreases, the WKB approximation breaks down so that these two focusing effects become

separate phenomena. They are intimately related to the concept of waveguide invariants (Chuprov, 1982; Brekhovskikh and Lysanov, 1991; D'Spain and Kuperman, 1999).

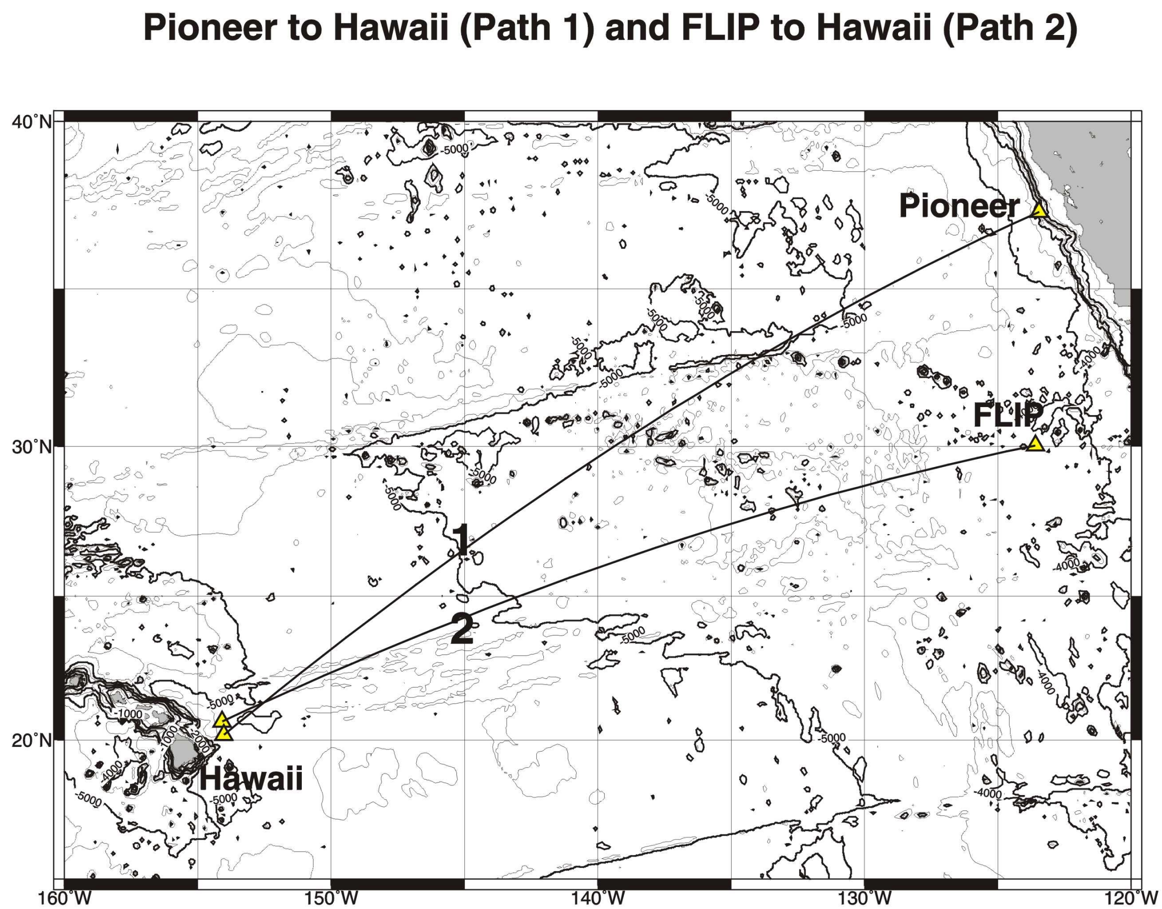

Figure 2. A map of the Northeast Pacific Ocean with superimposed ocean bathymetry contours showing two great circle paths. The path labeled "1" corresponds to the ATOC path from the source at Pioneer Seamount to the vertical receiving array off the northeast coast of Kauai and is the path traveled by the signal plotted in Fig. 1. Path "2" is that of the Acoustic Engineering Test (AET), also part of the ATOC program.

Fig. 3 shows a plot of the "effective" mode group velocity (i.e., inverse of range-averaged group slowness assuming adiabatic mode propagation) as a function of phase velocity at the receiver location for the ATOC Path 1 in Fig. 2. Curves for each of the integral frequencies from 60 to 90 Hz are plotted so that the two focusing effects can be examined simultaneously. These curves were calculated using the Kraken normal mode code (Porter, 1995), freely distributed at the Ocean Acoustics Library web site (http://oalib.saic.com/) with input environmental information extracted from an ocean climatology data base. Several plateaus occur at places where the curves also are tightly bunched together, indicating a simultaneous combination of broadband focusing and WDBR effects. The two plateaus, one at a phase velocity of about 1495 m/s (and effective group velocity of about 1482.5 m/s) and the other at 1523 m/s, are those that presumably give rise to the two focus regions in the single element spectrogram in Fig. 1 since these corresponding mode groups appear to be the ones most effectively excited/received by the source/receiver depth combination.